GUIDELINES

FOR

FOUNDATION INVESTIGATIONS AND REPORTS

VERSION 1.2

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DIVISION OF ENGINEERING SERVICES
GEOTECHNICAL SERVICES

CONTENTS

1. INTRODUCTION

1.1 Purpose

The following information provides guidelines for typical structure foundation investigations and foundation reports for the California Department of Transportation (Caltrans).

The Offices of Geotechnical Design North, South, and West, of Geotechnical Services (GS), Division of Engineering Services, Caltrans, are responsible for providing geotechnical oversight of these foundation investigations and reports. The three Offices of Geotechnical Design will also act as the single points of contact representing GS with the Offices of Special Funded Projects (OSFP), Structures Contract Management (OSCM), and other Caltrans offices.

1.2 General Requirements

Foundation Investigation is required for all structures (bridges, tunnels, special design retaining walls, soundwalls, tieback walls, MSE walls, overhead signs, maintenance stations, pumping plants/stations, toll plazas, etc.) when new, widening, retrofit, or modifications to existing structures are proposed. Refer to Topic 829 of the *Highway Design Manual* (Caltrans, 2001a) for direction regarding the need for Structure Foundation Reports for culverts. Foundation Investigation generally consists of two stages: A Preliminary Foundation Report to support Advanced Planning Study and Type Selection, and a Final Foundation Report to support structure design and construction. (The Preliminary Geotechnical Design Report and Geotechnical Design Report for the roadway portion of a project shall be submitted separately from Structure Foundation reports.)

The Foundation Investigation shall be conducted and the Foundation Report developed and signed by a Registered Civil Engineer or Registered Geologist who specializes in foundation engineering for highway structures. The geotechnical professional of record shall include his/her State of California registration seal, license number, registration certificate expiration date, and signature on all submittals of Foundation Reports, addenda and/or amendments to the Foundation Reports, and Log of Test Boring (LOTB) sheets.

The Foundation Report with the Contract Plans **for each structure** shall be developed in accordance with Caltrans requirements including the guidelines herein. It shall also conform to generally accepted standards of professional practice and all applicable rules and regulations of the California Board of Registration for Professional Engineers and Land Surveyors and the California Board of Registration for Geologists and Geophysicists.

The Foundation Report shall consist of, but not be limited to, the following: cover sheet, table of contents, main contents, and appendices. The cover of Foundation Reports and numbered addenda/amendments to Foundation Reports shall include the following information: Caltrans District, County, Route, Kilometer Post (KP) Total Project Limits, State-assigned Bridge (or Structure) Number, State-assigned Bridge (or Structure) Name, and Expenditure Authorization (EA) number. All LOTB sheets submitted shall also contain the above information.

The Foundation Report shall address, but not be limited to, the following topics when applicable: scope of work, project description, field exploration, laboratory testing, site geology and subsurface conditions, groundwater conditions, geologic profiles and engineering parameters, seismic study, liquefaction evaluation, scour evaluation, corrosion evaluation, foundation recommendations, approach fill earthwork, settlement, slope stability analyses, and construction considerations.

The Foundation Report shall contain foundation recommendations that are complete, concise and definite. The recommended foundation type shall be cost-effective, performance-proven, and constructible. Alternative foundation types shall be discussed and the reasons why those alternatives are not recommended shall be stated. Solutions to potential construction problems shall be discussed.

It is Caltrans policy that existing structure foundations shall be evaluated according to the latest Caltrans design criteria when widening or retrofitting projects are initiated. The evaluation shall be made prior to the Type Selection Meeting and conclusions shall be included in the Type Selection Report/Preliminary Foundation Report. Foundation reports for projects previously approved by Caltrans but that have been shelved shall be updated and reviewed and approved by Caltrans in accordance with the latest Caltrans requirements when necessary.

It is imperative that the structural designer, geotechnical professional, engineering seismologist, corrosion engineer, hydrology and hydraulics engineer, and specifications engineer maintain close communication during the development of the Foundation Report, Contract Plans, and Special Provisions. Foundation recommendations as shown in the Contract Plans and Special Provisions shall be consistent with the Foundation Report.

Log of Test Boring (LOTB) sheets shall be drafted and submitted as part of the Foundation Report and Contract Plans. As-Built LOTB sheets shall be included as part of the Foundation Report and Contract Plans.

The site data may come from current or past field investigations at or near the structure site, As-Built documents, maintenance records, and construction notes. Relevant data used for developing the foundation recommendations shall be attached. All extraneous data shall be omitted. Use of any site information that has not been approved by Caltrans shall be verified in accordance with Caltrans requirements and reviewed and approved by Caltrans.

Any construction change orders that revise, modify, or affect original foundation recommendations shall be submitted to Caltrans for review and approval prior to any action taken by the contractor. Upon completion of construction, As-Built structure foundation documentation, including pile driving logs and construction notes, shall be submitted to Geotechnical Services, Division of Engineering Services, Caltrans for record-keeping.

In general, all of the requirements above apply to both Preliminary and Final Foundation Reports unless specified otherwise.

2. PRELIMINARY FOUNDATION REPORTS

A Preliminary Foundation Report (PFR) is required during the early stages of a project and shall be included as part of the Advanced Planning Study and Type Selection submittal. The PFR is used to document existing foundation conditions, make preliminary foundation recommendations, and identify the need for additional investigations and studies. The PFR shall provide, but not be limited to, the following:

2.1 Summary of Site Geology and Subsurface Conditions

This section shall provide a description of site geology and subsurface conditions based on As-Built and any relevant information. The information shall include:

1) topography and geology,
2) types of soil/rock and their engineering properties,
3) pertinent soil conditions or geologic hazards,
4) depth to the bedrock, and
5) groundwater elevation(s) and dates the measurements were made.

If these conditions are based on an extrapolation from information at a nearby site, this fact shall be noted and the applicability of the information to the project site shall be addressed.

2.2 Project Location

The structure's coordinates and a location/vicinity map shall be included in the PFR.

2.3 As-Built Data

The PFR shall include, but not be limited to, evaluation of the following As-Built data:

1) As-Built and any other applicable LOTB sheets;
2) As-Built plans showing existing types of shallow or deep foundations, abutments, etc.;
3) As-Built geotechnical ultimate compressive, tensile, and lateral capacities of existing foundations shall be estimated and discussed. Recommendations for the ultimate lateral passive resistance of soil located behind abutments shall be provided if applicable; and
4) construction records such as pile driving logs, pile load test reports, settlement monitoring data, groundwater monitoring notes, etc.

The validation and adequacy of As-Built soil/rock information for the proposed project shall be discussed. The evaluation shall be based on the following three basic criteria:

1) Soil/rock information shall be adequate to cover each and every support location in both longitudinal and transverse directions along a structure.
2) Depths of soil/rock investigation shall be deeper than those of proposed pile tips or footing bottoms in order to provide sufficient information of influencing parameters.
3) Soil/rock information shall be adequate for foundation design and construction.

A discussion of previous groundwater observations and recent observations shall be provided.

Based on the evaluation of existing data, recommendations for any additional field investigation shall be made. If additional field explorations are necessary, the scope and types of fieldwork shall be stated.

2.4 Seismic Study

Seismic study shall be performed as early as possible. Seismic study shall consist of both ground motion and the potential for surface ground rupture.

1) Ground Motion Study

   The requirements specified in **Section 3.7** shall be addressed as much as possible in the PFR. As a minimum, the following seismic ground motion information shall be provided in the PFR:

   a) Designation of controlling active fault(s), the style of faulting, the magnitude of Maximum Credible Event (MCE), the fault-to-site distance, and the Peak Bedrock Acceleration (PBA);
   b) Recommended Acceleration Response Spectra (ARS) for defined soil profiles;
   c) If applicable, site-specific seismic hazard evaluation and ground motion study; and
   d) If necessary, recommendations for in-situ data acquisition and laboratory testing to obtain site-specific data such as shear and/or compressive wave velocities, strain dependent shear moduli, and damping ratios.

2) Fault Rupture Study

   A Fault Rupture Investigation and a stand-alone Fault Rupture Report is required when:

   a) The structure is within a published seismic hazard zone (e.g., Alquist-Priolo earthquake fault zone), or
   b) Other information (consultant reports, county reports, graduate theses, etc.) exists that indicates the possibility an active fault crosses or is within 100 meters of the structure.

   If fault rupture investigation is not needed, it shall be noted in the PFR.

   The Fault Rupture Investigation should include geologic studies and seismic fault rupture analysis.

   The geologic studies included in a Fault Rupture Investigation should conform to established guidelines (e.g., DMG *Note 49*). The investigation should include a geologic evaluation including literature review/summary, geologic mapping, air photo interpretation, trenching, geophysical surveys, etc.

   Based on geologic studies, if it is determined that there is a potential for fault rupture hazard, and the structure is to be located either within 15 m (50 feet) of a known fault or the possibility of a fault rupture passing through the proposed structure cannot be excluded, then seismic fault rupture analysis should be performed. This may include, but not be limited to magnitude, slip rates and recurrence models, type of fault (e.g., strike slip, normal), horizontal and vertical components of offset, style of faulting (primary or secondary), fault orientation, probabilistic and/or deterministic fault displacement hazard analysis, and risk analysis. Analyses should be based on published data (e.g., U.S. Geological Survey and DMG publications) and/or field-collected data. Correlation between fault rupture displacement and fault magnitude (e.g., Wells and Coppersmith, 1994) may be modified by findings in the geologic studies.

If secondary faulting is proposed as a design fault rupture event, then the methodology to represent the secondary faulting shall be included in the Fault Rupture Investigation Report.

For Ordinary Structures, the Return Period for the Probabilistic Fault Rupture Hazard Analysis may be in the range of 1500 to 5000 years.

Recommendations for design fault rupture movements (horizontal and vertical) and concurrency of design fault rupture movements and design ground motions shall be presented in the Fault Rupture Investigation Report.

2.5 Liquefaction Evaluation

The PFR shall include an assessment of the liquefaction potential at the project site, and its possible effects on the existing and/or proposed foundations. The PFR shall outline a proposed field and laboratory program that will be capable of obtaining reliable data for a quantitative evaluation of liquefaction and its consequences.

2.6 Scour Evaluation

The geotechnical professional shall incorporate the hydraulic findings outlined in the structure Hydrology/Hydraulics Report with geologic and geotechnical information to make recommendations regarding the scour depth. The effects of scour on existing and proposed foundations shall be addressed.

2.7 Corrosion Evaluation

The PFR shall include any available corrosion data for the site and a discussion of such data. If corrosion data for the site is not available, or is insufficient to provide conclusive information regarding the corrosiveness of the site, additional corrosion sampling and testing shall be required per Caltrans guidelines. *Interim Corrosion Guidelines for Foundation Investigations* (Caltrans, 1999a) may be obtained from the Corrosion Technology Branch, of Materials Engineering and Testing Services, Division of Engineering Services.

2.8 Preliminary Foundation Recommendations

The PFR shall provide preliminary foundation recommendations as follows:

1) assumptions used for making preliminary foundation recommendations,
2) proposed foundation types, support locations, estimated geotechnical capacities, and foundation dimensions or pile tip elevations,
3) design groundwater table,

4) alternative foundation types with their advantages and disadvantages, and
5) construction considerations.

2.9 Additional Field Work and Laboratory Testing

The PFR shall state the scope and type of fieldwork and laboratory testing required to develop final foundation recommendations. It is prudent to plan in advance and obtain sufficient support-location specific soil/rock information that meet the three basic criteria discussed in **Section 2.3**.

3. FOUNDATION REPORTS

Consultant-prepared Final Foundation Reports shall be submitted as early as possible to Caltrans for review and approval. Technical discussions between the consultant and Caltrans reviewer are encouraged during any stage of the project development.

The Final Foundation Report shall address, but not be limited to, the following topics when applicable:

3.1 Scope of Work

This section shall summarize the scope and types of work performed to obtain the information supporting the foundation recommendations.

3.2 Project Description

This section shall describe the project location, existing and/or proposed structure(s), and pertinent project information. A site vicinity map indicating the project location shall be included in the Appendices.

3.3 Field Exploration

Field exploration shall be performed when necessary to provide information for foundation design and construction. It is prudent to plan in advance and obtain sufficient support-location specific soil/rock information that meet the three basic criteria as discussed in **Section 2.3**. The extent of exploration depends on the degrees of variability and irregularity of subsurface conditions, nature and type of the structure, dynamic and static loads, and other relevant factors.

Typical sampling intervals for soil are 1.5 m (5 feet) or less in homogeneous strata with test and sampling locations at every change of strata. When weathered rock or shale is encountered, the Standard Penetration Test shall be made at the top of the weathered rock or shale and continued until refusal is met in accordance with current *ASTM D 1586*.

Descriptions of the field exploration program including drilling, in-situ testing, disturbed and/or undisturbed sampling, and logging activities are required. For logging methods refer to *Soil & Rock Logging Classification Manual* (Caltrans, 1996a), *Engineering Geology Field Manual* (USBR), ASTM, or other published and approved logging systems.

Field data incorporated with laboratory data shall be summarized on the LOTB sheet(s).

When current foundation studies involve literature searches of past foundation studies and As-Built records, the pertinent information shall be included and sources cited. In-situ testing and logging data, LOTB sheets, and relevant field information shall be included in Appendices.

3.4 Laboratory Testing

Laboratory testing on soil, water, and rock samples shall be performed in accordance with current AASHTO, ASTM, or *Standard Test Methods* (Caltrans).

1) Geotechnical Laboratory Testing
   These tests shall be sufficient to determine the following properties of foundation materials: soil/rock classification, permeability, compressibility, shear strength, unconfined compressive strength, expansion characteristics, and slake susceptibility. Soil/rock test data shall be included in Appendices. Locations and types of testing shall be indicated with symbols at the relevant elevations on the LOTB. Results from moisture and density tests shall be shown on the LOTB. Visual classification of earth materials based on field inspection shall be confirmed or revised with laboratory test data as necessary. A note stating such a confirmation or revision shall be included on the LOTB.
2) Corrosion Testing
   Obtaining representative soil and water samples for corrosion testing shall be part of the field exploration program. Corrosion sampling and testing shall be consistent with Caltrans guidelines. *Interim Corrosion Guidelines for Foundation Investigations* (Caltrans, 1999a) may be obtained from the Corrosion Technology Branch, of Materials Engineering and Testing Services, Division of Engineering Services. The following California Test Methods (i.e., *Standard Test Methods*) are required to assess the corrosivity of a site:
   a) California Test 643, Parts 2 & 3 for determining pH of soil and/or water,
   b) California Test 643, Part 4 for obtaining minimum soil resistivity,
   c) California Test 417 for sulfate content of soil and/or water, and
   d) California Test 422 for chloride content of soil and/or water.

3.5 Site Geology and Subsurface Conditions

An overview of the site topography and geology is required. Historical and/or potential geologic hazards such as landslides and other slope failures, ground subsidence, collapse, heave, earthquakes, and floods shall be characterized.

1) It is vital to collect reliable groundwater data, regardless of site exploration method. Groundwater information, which has profound effects on foundation design and construction, shall contain:
   a) types of groundwater - static water table, upper zone (perched water, capillary water, gravity or vadose water, etc.), or saturated zone (phreatic surface, confined water, or aquifer);
   b) artesian conditions, springs, and underground streams if present;
   c) dates and elevations of groundwater surfaces encountered in the field;
   d) observation well readings, piezometers readings, and /or pumping test data;
   e) measurements of the groundwater table shall be made after completion of drilling and stabilization of the groundwater table. Measurement is still required when rotary-wash drilling is performed;
   f) recommended design groundwater table; and
   g) anticipated problems of groundwater for foundation construction and solutions to these problems.

2) The following information for bedrock shall be addressed:
   a) If bedrock is encountered in the field study, the elevations and locations shall be included. (Note: Continuous coring is required in bedrock; see *ASTM D 2133*.) Effects of the estimated rock profiles on ground motions shall be addressed. Effects of the rock profiles on foundation design and construction shall be addressed.
   b) If bedrock is not encountered within the depth of investigation, the depth to bedrock and shear/compression wave velocities for the bedrock at the site shall be estimated based on the local geology. Effects of the estimated rock profiles on ground motions shall be addressed.
   c) If spread footings, piles, or drilled shafts are to be founded on or embedded into rock, rock-mass characteristics shall include, but not be limited to, the following:
      i) type of fracture(s) (fault, bedding plane, foliation, and joint),
      ii) orientation of fracture(s) (dip, dip direction, and strike), and
      iii) other engineering properties (unconfined compressive strength, shear/compressive wave velocities, etc.).
   d) Where rock-mass discontinuities are relevant to the design, construction, or performance of the foundation, the following shall be addressed:
      i) stereographic projection (pole plots, density, and great circles), and
      ii) kinematic analysis (planar failure, wedge failure, toppling failure, etc.).
3) When potential landslides or other failures pose hazards to the foundations, detailed terrain analysis, structural features study, and other geologic investigations shall be performed. Remediation measures shall be presented. Structure foundations shall not be used as any part of the landslide remediation measures.
4) If soil conditions such as Collapsible Soils, Corrosive Soils, Expansive Soils, Frost Heave Susceptible Soils, Frozen Soils, Liquefiable Soils, or Sanitary Landfill are encountered at the project site, this information from field exploration and laboratory tests, including groundwater and index properties of soils, shall be documented. Effects of these problematic soils on foundations and the proposed mitigation measures shall be discussed when developing foundation recommendations.

3.6 Geologic Profiles and Engineering Parameters

Representative soil/rock profiles derived from field information, laboratory data, and As-Built records shall be provided at each support location for foundation design and analysis. These profiles shall contain soil/rock types, layers, groundwater surface, and essential engineering parameters. A discussion on the selection of engineering parameters is required. When published correlation relationships are used to determine the engineering parameters, references shall be given. It is required that any interpolation or extrapolation on soil/rock profiles and properties be made based on existing evidence in conjunction with sound engineering judgment.

A conversion ratio between penetration tests not performed per *ASTM D 1586* and standard SPT shall be discussed and provided, if applicable. This includes nonstandard samplers, nonstandard hammer energy delivery systems, and considerations of hammer efficiency.

It is imperative that soil/rock profiles be used consistently throughout foundation design and analyses.

3.7 Seismic Study

General ground motion seismic design requirements are specified in *Caltrans Seismic Design Criteria* (*SDC*, Caltrans, 2001b). Seismic study in the Foundation Report shall include, but not be limited, to the following:

1) Active Faults and Peak Bedrock Acceleration

   Active faults that have the potential to affect the project shall be identified in accordance with *Caltrans California Seismic Hazard Map and Report 1996* (*CSHM*, Caltrans 1996b), or its latest revision. The Maximum Credible Earthquake (MCE) magnitude, the style of faulting, the fault-to-site distance, and the horizontal Peak Bedrock Acceleration (PBA) at the site shall be provided. The magnitude of MCE and PBA shall be determined using the latest version of *CSHM*.

   The PBA determined above shall be verified with well-established attenuation relationships for controlling fault(s). The style (fault type) of controlling fault (s) shall be considered in determining PBA according to the attenuation relationships presented by Sadigh *et al.* (1997). If discrepancy exists between *CSHM* and the attenuation relationships, discussion shall be made and the suggested PBA shall be submitted for Caltrans approval.

2) Acceleration Response Spectra (ARS) Curves

   ARS in accordance with the current *SDC* shall be selected for ordinary standard (as defined in *Bridge Memo to Designers 20-1* (Caltrans, 1999b)) bridge structures in conjunction with MCE and PBA. The corresponding *SDC* soil profile shall be specified and the design ARS shall be attached. The selected ARS curves from *SDC* shall be modified as follows:

   a) When the structure is located within 15 km (10 miles) of the controlling fault(s), the standard *SDC* ARS shall be modified as follows to account for fault rupture directivity effect:
      i) spectral ordinates for periods equal to or greater than 1.0 second are increased by 20%;
      ii) no change is required for spectral ordinates for periods less than 0.5 second; and
      iii) spectral ordinates for periods between 0.5 and 1.0 second shall be determined by linear interpolation.

   b) When the fundamental period of a bridge structure is greater than 1.5 seconds and the depth to rock-like material is greater than 75 m (250 feet), the standard *SDC* response spectra shall be modified as follows:
      i) spectral ordinates for periods equal to or greater than 1.0 second are increased by 20%;
      ii) no change is required for spectral ordinates for periods less than 0.5 second; and

iii) spectral ordinates for periods between 0.5 and 1.0 second shall be determined by linear interpolation.

c) The combined effects of fault type (from PBA) and directivity on ARS shall be discussed and judgment shall be made in determining the recommended ARS.

3) Site-Specific ARS

a) Site-specific analysis may be required for bridges more than 300 m (1000 feet) in length.

b) Site-specific analysis for ground motion may be performed when the design earthquake has a moment magnitude greater than or equal to 6.5 and one or more of the following conditions exist:

i) bridge structure located at or near fault(s),

ii) presence of deep soft soils or liquefiable soils,

iii) structure of long periods, or

iv) other special cases.

4) Fault Rupture

When bridge structures are subject to fault rupture displacements, the magnitude and direction of displacement shall be recommended for design. See **Section 2.4**.

3.8 Liquefaction Evaluation

When the field investigation reveals that potentially liquefiable soils and conditions including lateral spreading exist and they pose a hazard to the project site, a quantitative geotechnical evaluation of such a potential shall be conducted. In-situ testing, soil sampling, and laboratory testing on potentially liquefiable soils must be properly planned and conducted to obtain reliable data for the geotechnical evaluation. If liquefaction is likely to occur, its consequences shall be assessed, its impact on foundations shall be addressed, and mitigation measures shall be specified. Design Elevations of the liquefiable layer(s) shall be presented in the Foundation Report. Assumptions, analytical or empirical methods used, and conclusions for liquefaction evaluation shall be stated with relevant data and analysis attached in Appendices.

3.9 Scour Evaluation

The geotechnical professional shall incorporate the hydraulic findings outlined in the structure Hydrology/Hydraulics Report with geologic and geotechnical information to make recommendations regarding the scour depth. The effects of scour on existing and proposed foundations shall be addressed.

3.10 Corrosion Evaluation

This section shall contain an assessment of the corrosiveness of a site based on the review of relevant corrosion test data. Corrosion test data shall be included in Appendices. Sufficient information regarding the number and location of soil borings for corrosion testing shall be included to allow a thorough review of the recommendations.

3.11 Foundation Recommendations

Complete, concise, and definite foundation recommendations shall be provided for the referenced structure. The selection of a specific foundation type depends on factors such as surface and subsurface conditions at the site, geotechnical capacity, dynamic and static demands, environmental concerns, economics, and construction issues. The recommended foundation type shall be cost-effective, performance-proven, and constructible. Alternative foundation types shall be discussed and the reasons why those alternatives are not recommended shall be stated. Solutions to potential construction problems shall be discussed. A sufficient and adequate geotechnical evaluation for the recommended foundation shall be performed.

In general, any foundation design shall meet five essential requirements: (1) adequate safety against structural failure of the foundation (which shall be addressed by the structural engineer); (2) adequate geotechnical capacity of soil/rock surrounding the foundation with a specified safety against ultimate failure; (3) acceptable total or differential settlements under static and dynamic loads; (4) adequate overall stability of slopes in the vicinity of a footing; and (5) constructibility with solutions for anticipated problems.

For **Shallow Foundations**, the geotechnical professional shall address, but not be limited to, the following when applicable:

1) Bearing/Lateral Capacity and Factor of Safety (See **Section 5.3** regarding Spread Footing Data Table)
    a) footing width (B), length (L), and minimum depth (D) at the bottom of footings or the maximum elevation at the bottom of footings
    b) ultimate soil/rock bearing capacity (q_{ULT}) and allowable soil/rock bearing capacity (q_{ALL}) with a specified Factor of Safety (F.S.) or Strength Reduction Factor (ϕ)
    c) indication whether the q_{ULT} and q_{ALL} are GROSS or NET at the elevations specified (Note: The 'FOOT' computer program requires the NET q_{ALL} as input and computes a GROSS q_{ALL} based on the amount of cover and considers the overburden and column/footing weights as imposed loads)
    d) effects of soil density, groundwater table, seepage, load eccentricity and/or inclination, or layered soils on bearing capacity
    e) foundations on slopes, adjacent to slopes, or with inclined bases
    f) passive pressure behind an abutment. For ultimate soil passive pressure behind an abutment using Caltrans standard structure backfill, please refer to the latest version of *SDC* Section 7.8. Re-evaluation of the ultimate soil passive pressure behind an abutment shall be made for any backfill material other than Caltrans standard backfill (the values specified in *SDC* Section 7.8 shall not be used in such cases).
    g) sliding resistance or key requirements (Note: sliding resistance shall be calculated using 50% of base resistance plus 50% of passive resistance behind the footing, or, 100% of base resistance only, or, 100% of passive resistance only)
    h) vertical and lateral movement of abutments under seismic condition

i) foundation failure modes where foundations are founded on or embedded into rock.

2) Total, Differential, and Tolerable Settlements
   a) Total and differential footing settlement shall be estimated for both working loads and seismic loads.
   b) Differential settlement across a support and differential settlement between supports shall not exceed 13 mm (0.5 inch).
   c) Any total foundation settlements shall not exceed a tolerable level as established by considering structural integrity, foundation stability, and maintenance requirements.
   d) Estimates of any settlement periods shall be provided.
   e) Methods of pre-loading and/or de-watering shall be discussed if applicable.

3) Overall stability of slopes in the vicinity of a footing under both working loads and seismic loads.

4) Other Considerations for Shallow Foundations
   a) In regions where freezing of ground occurs during winter seasons, footings shall be founded below the maximum depth of frost penetration by excavation of frost-susceptible soil to below the frost line and replacement with non-frost-susceptible materials.
   b) The top of footings or other shallow foundations shall be founded below the maximum anticipated depth of scour at water crossings.
   c) A geotextile or graded granular layer shall be considered for reducing susceptibility to piping in riprap or abutment backfill if applicable.
   d) Pile foundations shall be used at abutments when PBA is 0.6g or greater, and the embankment height is 3 m (10 feet) or greater, or if the bents are on piles and significant densification (settlement) of the foundation material during and after earthquake can be expected. The exception to this recommendation is for abutments under single span bridges. These may have either pile or spread footings per *Bridge Memo to Designers 5-1* (Caltrans, 1992).
   e) Where footings are placed adjacent to existing structures, the effect of the existing structures on the performance of the new footing and the influence of the new footing on the adjacent structures, including construction activities, shall be discussed.
   f) When footings are subject to uplift forces, footings shall be evaluated for resistance to pullout and for their structure strengths.
   g) Engineering analyses and calculations shall be included in Appendices. This information shall be legible, organized, and understandable.

For **Deep Foundations**, the geotechnical professional shall address, but not be limited to, the following when applicable:

1) Pile Types, Bearing Capacity, and Settlement

a) Recommended pile types shall be identified as driven Cast-In-Steel-Shell (CISS) piles, Cast-In-Drilled-Hole (CIDH) piles with/without casing/shell, Precast Prestressed Reinforced Concrete piles, Steel HP Piles, or others. Alternatives shall be discussed and the reasons why those alternatives are not recommended shall be stated.

b) Caltrans Standard Class 400, 625 and 900 piles (*Standard Plans* (Caltrans, 1999c)) may be used up to a maximum Nominal Resistance in Compression/Tension of 800/400, 1250/625 and 1800/900 kN, respectively.

c) Whether compressive and/or tensional geotechnical capacities are derived from skin friction, end bearing, or a combination of both for a single or group pile(s) shall be discussed.

d) Pile Design Tip Elevations (DTE) may be controlled by demands from compression, tension, lateral loads, scour potential, or liquefaction. The pile Specified Tip Elevation (STE) equals the lowest pile DTE as estimated above.

e) The portion of the axial capacities for pile foundations in and above liquefiable soils shall be neglected.

f) The portion of the axial capacities for pile foundations above the maximum scour depth shall be neglected. (For earthquake loading conditions, see Section 4.4.5.2 of *Bridge Design Specifications* (Caltrans, 2000a).)

g) Negative skin friction (down-drag) on pile shaft due to settlements of new fills or compressible soil layers shall be eliminated prior to pile installation. Recommendations to eliminate the development of negative skin friction on pile shaft shall be included.

h) When a situation such as liquefaction potential exists that does not allow for mitigation and elimination of negative skin friction, the magnitude of the down-drag forces shall be estimated and provided to the structural designer for him/her to incorporate those forces into Design Loading or Nominal Resistance. The magnitude of estimated settlement shall also be provided to the structural designer. An iterative process may be required between the geotechnical professional and structural designer before the final pile type and diameter is selected.

i) For piles driven through scourable layers and/or potentially negative skin friction layers, the geotechnical professional shall provide an estimate of the pile driving resistance to reach STE. Non-liquefied conditions shall be considered for pile driving resistance.

j) When any overburden pressure from recently placed or proposed fill materials (such as embankments) is to be used in the static pile capacity calculations, discussion of pressure distribution shall be included. The embankment prism shall not be construed as unlimited.

k) Pile foundations shall be used at abutments when PBA is 0.6g or greater and the embankment height is 3 m (10 feet) or greater, or if the bents are on piles and significant densification (settlement) of the foundation material during and after earthquake can be expected. The exception to this recommendation is for abutments under single span bridges. These may have either pile or spread footings per *Bridge Memo to Designers 5-1* (Caltrans, 1992).

l) Lateral pile capacity shall be estimated using the p-y method or equivalent. Group reduction factors depending on soil types, pile spacing, and anticipated lateral movement shall be considered when evaluating lateral capacity for a group of piles. Formulation of p-y curves for liquefiable soils and weak rocks, effects of pile diameters on lateral soil modulus and soil strain parameters, evaluation of liquefaction or lateral spreading forces imposed on pile, and reduced moment of inertia for concrete piles shall be addressed.

m) The single and/or group pile settlement shall not exceed the tolerable amount as established by the structural designer.

2) Pile Data Table (PDT) per *Bridge Memo to Designers 3-1* (Caltrans, 2000b)

a) A structural designer applies the Working Stress Design (WSD) approach or the Load Factor Design (LFD) method to calculate loads on foundations and designs structural members (steel, concrete, reinforced concrete, etc.) of foundations accordingly. For a given foundation type at a particular support location, a structural designer uses either WSD to determine **Design Loading** or LFD to calculate required **Nominal Resistance** on foundations. It is common practice to calculate **Design Loading** at locations of abutments and retaining walls and to calculate required **Nominal Resistance** at locations of bents or piers.

b) At locations of bents or piers, a geotechnical professional shall determine pile tip elevations to meet the required **Nominal Resistance**. The geotechnical professional shall convert the required **Nominal Resistance** to a **Design Loading** for driven piles when the Engineering News-Record (ENR) formula is used for field acceptance criteria per Section 49-1 of *Standard Specifications* (Caltrans, 1999d). As such, both converted **Design Loading** and required **Nominal Resistance** shall be shown in the PDT for driven piles. The conversion is not required for the following: if Pile Data Analyzer (PDA) and/or Pile Load Test are proposed for pile installation instead of using the ENR formula, or, CIDH piles are used. Insert "N/A" in the **Design Loading** column in the PDT for these cases.

c) At abutments or retaining walls, the geotechnical professional shall convert the **Design Loading** to a required **Nominal Resistance,** determine pile tip elevations accordingly, and show both values in the PDT.

d) When pile foundations are designed to provide only lateral resistance and no axial capacities are required, pile tip elevations shall be controlled by lateral demand. The geotechnical professional shall insert "N/A" in both **Design Loading** and required **Nominal Resistance** columns in the PDT and make a note such as "**pile tip shall not be raised; pile only provides lateral resistance with no axial capacities required**" for that entry below the PDT.

e) When pile foundations are controlled by earthquake loads (e.g., a retrofit project), the geotechnical professional shall: convert the required **Nominal Resistance** to a **Design Loading** for driven piles if the ENR formula is used for field acceptance criteria, or, insert "N/A" in the **Design Loading** column for CIDH piles.

f) Examples of PDT can be found in *Bridge Memo to Designers 3-1* (Caltrans, 2000b).

3) Special Considerations for Cast-In-Drilled-Hole (CIDH) Piles

a) Designers shall show on the plans standard metric sizes for CIDH concrete piling. See *Bridge Memo to Designers 3-1* (Caltrans, 2000b) for sizes.

b) To ensure constructibility and quality, the length of CIDH piles should be limited to 30 times the pile diameter.

c) When battered piles are required, CIDH piles shall not be used because of the increased risk of caving and the difficulty of placing concrete in a sloping hole.

d) The following nomenclature is used for CIDH piles: steel *casings* are used for constructibility, while driven steel *shells* are used for pile capacity.

e) Where a steel casing/shell is required, the diameter of the casing/shell shall be at least 200 mm greater than the CIDH pile or rock socket diameter.

f) If pile tips are below the groundwater table or wet construction method is used, CIDH piles shall be designed at a diameter equal to or greater than 600 mm (24 in).

g) Gamma-Gamma testing shall be performed on CIDH piles installed underwater.

h) When CIDH piles diameters are less than or equal to 600mm (24 in), no end-bearing is allowed.

i) When permanent steel shells for CIDH piles are used to develop a portion of the axial and/or lateral capacity, the shells shall be installed by driven methods using impact hammers only.

j) When permanent casings for CIDH piles are used and they are not required to carry axial and/or lateral loads, the report shall state that only the CIDH piles extending below the casings are designed to develop the required Nominal Resistance.

k) The elevations of the bottom of footings or cut-off elevations for CIDH piles shall be specified for design.

l) In general, if temporary casings for CIDH piles are installed/retrieved in accordance with *Standard Specifications* (Caltrans, 1999d) and Special Provisions, the impact of casing installation/retrieval on pile capacities may be neglected.

4) Special Considerations for Driven Piles

a) When driven, open-ended CISS piles are recommended, the minimum soil plug, use of tremie seal, center relief/drilling, use of end bearing, etc., shall be addressed.

b) Undersized predrilling for driven piles may have impacts on the vertical and lateral capacities. A pile load test program may be considered in such cases.

c) Use of the Engineering News-Record (ENR) Formula

i) A pile driving formula such as the ENR equation, as adopted in Section 49-1 of *Standard Specifications* (Caltrans, 1999d), may be used to verify bearing capacity for driven piles (note: the equation in Section 49-1 gives a bearing value, known as a safe load, which shall not be less than the design load shown in the PDT in the Contract Plans and Foundation Report). In every such formula the calculated ultimate bearing capacity relies on the penetration length under the last stroke or fall of the hammer, which leads to the conclusion that the ultimate bearing capacity of piles is practically independent of depth. This inherent feature demonstrates that any pile-driving formula is not suitable to friction piles in soft silt or clay where the end bearing is usually disregarded. Even for end-bearing piles and combination piles which the penetration resistance increases with depth, the geotechnical professional should be aware of the limitation of the use of any pile-driving formula to predicate the ultimate bearing capacity of driven piles.

ii) If driven piles do not develop the required bearing value based on the ENR equation, a setup time shall be specified for re-tapping piles.

d) Use of Wave Equation Analysis Program (WEAP), Pile Driving Analyzer (PDA)

i) For a given pile at particular soil conditions, driven by a specified hammer, WEAP can be performed to predict ultimate pile capacity as a function of the resistance to penetration in blows per 0.30 m (1.0 foot) of penetration. WEAP analyses shall be performed for driven piles with diameters equal to or greater than 600 mm (24 in).

ii) Pile Driving Analyzer (PDA), based on wave propagation theory, can be used for measuring soil resistance encountered and maximum internal pile forces both in compression and tension developed during pile driving. PDA can provide information with regard to hammer performance, pile integrity, and the pile axial capacity associated with each blow of the hammer. Wave equation analyses and PDA can be used for monitoring pile driving and measuring pile capacity as required by the geotechnical professional in the Foundation Report.

5) Pile Load Test

Indicator Pile Load Test (IPLT) can be used for determining pile capacity at failure (ultimate capacity), and for establishing field acceptance criteria. A load test remains the definitive way to determine whether the professional's estimate of capacity and specified tip elevations is appropriate in design and to determine whether the production piles meet the specifications during construction. The equipment and procedures for conducting pile axial compressive load tests can be found in literatures such as *ASTM D 1143*.

a) Static axial tension tests shall be performed per *ASTM D 3689*.

b) Static lateral load tests shall be performed per *ASTM D 3966*.

c) Pile load tests should be performed for unusual site conditions, important bridge structures, large-diameter driven piles or large-diameter CIDH (diameter equal to or greater than 1.2 m) piles, foundations supported by one or a few large-diameter pile(s) (with little redundancy), or combination of above. Pile load tests shall be recommended by the geotechnical professional with concurrence of the project engineer. When pile load tests are recommended, a table summarizing pile load test control locations, types of load tests (compression, tension, or lateral loads), STEs, and Nominal Resistances shall be specified.

d) Caltrans field acceptance criterion is a maximum of 13 mm (0.5 in) of vertical movement at the top of the pile at the Ultimate Geotechnical Capacity both for compression and tension.

e) When pile load tests are conducted, results shall be used for establishing field acceptance criteria for production piles in conjunction with use of wave equation analyses, PDA, or ENR.

f) Whenever pile load tests, wave equation analyses, and PDA are conducted on a construction project that is locally administered, copies of the field test results, analyses and drawings of locations of tested piles (or copies of pertinent contract plan sheets) must be submitted by the Local Agency Resident Engineer (or its consultant construction contract administrator) to Caltrans. A cover letter must accompany the load test results that states the Bridge Name, Bridge Number, the pile load test location, Contract EA number, the name and address of the contractor/consultant firm that performed the pile load tests, and the date that the tests were performed. The Caltrans Oversight Structure Representative requires a copy of the cover letter only. For construction projects that are State-advertised and administered, Caltrans' Foundation Testing Branch, of the Office of Geotechnical Support, Geotechnical Services, will perform the pile load tests and file a copy of the test results, analyses, and drawings.

6) Other Considerations

a) Concrete cover and mix design requirements for CIDH piles and concrete piles shall be consistent with Section 8.22 of *Bridge Design Specifications* (Caltrans, 2000c).

b) When steel piles/shells are used in corrosive environments, corrosion mitigation measures shall be required. Caltrans typically includes a corrosion allowance (sacrificial metal loss) for steel piles in corrosive environments. Other corrosion mitigation measures may include coatings and/or cathodic protection. Information regarding corrosion mitigation measures for steel piles is available in *Interim Corrosion Guidelines for Foundation Investigations* (Caltrans, 1999a). This document may be obtained from the Corrosion Technology Branch, of Materials Engineering and Testing Services, Division of Engineering Services.

c) Assume that all of the degradation scour and none of the maximum anticipated local scour (local pier and local contraction) has occurred when designing for earthquake loading, per Section 4.4.5.2 of *Bridge Design Specifications* (Caltrans, 2000a).

d) Passive soil resistance around the bent cap shall be neglected unless detailed soil information from field exploration is available in that area. The area of structure backfill surrounding a bent is typically limited; therefore native soil properties shall be used in determining passive soil resistance around the bent cap.

e) Engineering analyses and calculations shall be legible, coherently organized, and included in Appendices.

For **Approach Fill Earthwork**, the geotechnical professional shall address, but not be limited to, the following when applicable:

1) Approach Fills
   a) Expansive Soils - the potential expansion of in-place or imported fill materials shall be addressed. Expansive soil materials shall not be placed as part of the embankment within the limits of a bridge abutment for the full width of the embankment. Expansive soil materials for this requirement are defined as having either an Expansion Index (EI) greater than 50 (EI to be determined in accordance with *ASTM D 4829*), or a Sand Equivalent (SE) less than 20 (SE to be determined in accordance with California Test 217). This requirement is exclusive of the structure backfill and pervious backfill material requirements as shown on the plans and set forth under Sections 19-3.06 and 19-3.065, respectively, in the *Standard Specifications* (Caltrans, 1999d). The limits (Figure 1) for placement of any in-place or imported fill material that is defined as expansive soil shall be included within the Foundation Report and Contract Plans.
   b) The limits of clearing and grubbing of vegetation shall be defined.
   c) When unsuitable material is to be stripped and removed or re-compacted, the depth and limits shall be defined.
   d) The limits of new fill placement, both horizontal and vertical, shall be defined.

2) Approach Fill Settlements - When newly placed approach fills induce settlement, the geotechnical professional shall provide the following information and recommendations:
   a) estimates of the magnitudes of settlements,
   b) required waiting periods/time delay,
   c) recommendations for surcharge loads and reduced waiting periods when applicable,
   d) when the rate of consolidation of approach fills is controlled by weak underlying soils, rates of loading along with site monitoring (piezometers) shall be specified, and
   e) recommendations for monitoring fill settlement.

3) Additional Considerations - The geotechnical professional shall provide discussion if any of the following is applicable:
   a) use of lightweight fill to reduce the magnitude of settlement
   b) use of wick drains or sand drains to accelerate settlement
   c) use of Geo-synthetic materials to improve shear strength and/or drainage
   d) use other soil improvement technology (densification, grouting, etc.)
   e) recommendations of vegetation or pavement for embankment side slopes and bridge approaches
   f) slope protection
   g) predrilling for any piles through fill
   h) recommendations for lengthening structure to eliminate significant embankment settlements.

3.12 Slope Stability Analyses

The overall stability of footings, slope, and foundation materials shall be evaluated for footings adjacent to or at the slope for both static and dynamic loading conditions.

Minimum required factors of safety for static conditions are specified in Section 4.4.9 of *Bridge Design Specifications* (Caltrans, 2000a).

Pseudo-static analyses may be used to determine slope stability, provided the soils are not liquefiable or expected to lose shear strength significantly during deformation. Pseudo-static analyses shall add (to other forces acting on the element) a horizontal force equal to the element weight times the following: a seismic factor equal to one third of the horizontal peak acceleration and not exceeding 0.2g. The effects of vertical acceleration may be omitted. Sites with a pseudo-static factor of safety equal to or greater than 1.1 shall be considered to have adequate stability and require no further stability analyses.

Sites with a pseudo-static factor of safety less than 1.1 will require dynamic displacement analysis (e.g., Newmark-type analysis). The displacement analysis shall determine the magnitude of potential ground movement for use by the structural designer in determining its effect upon the performance of the structure to meet the design performance level. Iteration may be needed for soil-structure interaction analysis.

Slope instability caused by lateral spreading/global instability due to liquefaction shall be considered if applicable. These analyses can be incorporated with an evaluation for a particular foundation type (see **Section 3.8**).

3.13 Construction Considerations

Constructibility study is the integration of construction expertise into the planning and design of a project so that the construction forces have the maximum opportunity to deliver the project in conformance with the owner’s quality, cost, and schedule objectives as well as eliminating or minimizing disputes and claims. To achieve these goals requires clear, concise, coordinated contract documents such as plans, specifications, special provisions, foundation reports, etc. It is imperative for the design team to examine construction strategies, techniques, and logistical issues so that the design can accommodate conceivable requirements. Constructibility issues shall be factored into the design as it evolves, potential construction problems shall be identified, and effective solutions to the problems shall be formulated and integrated into contract documents.

Construction considerations in the Special Provisions may be needed to address:

1) Control of groundwater and seepage during construction, in order to:
    a) provide a dry excavation,
    b) increase the stability of excavations, cut slopes, open-pits, or approach fills,
    c) improve the strength of foundation materials,
    d) reduce the lateral loads on supports in an excavation,
    e) prevent bottom heave and piping,
    f) cut off capillary rise,

g) accelerate consolidation and settlement, and
h) provide for effects due to fluctuations of the water table.

2) Control of groundwater and seepage after construction, in order to:
   a) reduce lateral pressures on retaining structures,
   b) reduce or cut off seepage and pore pressures beneath pavements, approach fills, abutment fills, cut slopes, and/or
   c) reduce or eliminate uplift pressure on the bottom of footings, drilled shafts and caissons.

3) Proposed control methods for groundwater, such as:
   a) cut-off and barriers (liners, blankets, membranes, sheet pile walls, slurry walls, concrete walls, soil mixing walls, grouting, tremie-seals, soil plugs, etc.),
   b) temporary or long-term de-watering systems (well points, sump pumps, electroosmosis, deep wells), and
   c) drains (trench drains, sand drains, wick drains, weep holes for retaining walls, stone column drains, etc.).
   d) If caving soil conditions and a high groundwater table exists for CIDH pile installation, wet specifications and/or temporary/permanent casing shall be considered. The geotechnical professional shall work with the specifications engineer in developing Special Provisions to address this issue.

4) Proposed control excavation methods requiring unusual techniques. These may include shoring, sheeting, bracing, special procedures, and variations in types of materials encountered.

5) Pile cut-off.
   When driven piles develop the required compressive capacities before reaching the STE, the Contractor may be given the option, with the Resident Engineer's approval, to stop driving and cut off the piles as long as the piles have achieved all the other design tip elevations controlled by tension, lateral, scour, and/or liquefaction and the structural capacity of the piles has not been compromised. Maximum cut-off length at the top of precast prestressed piles is three (3) meters per *Standard Plans* (Caltrans, 1999c). It should be noted that if the piles have corrosion protection coating, Caltrans' Corrosion Technology Branch shall also be contacted for approval of cut-off. Such potential situations and a recommended range of cut-off elevations shall be addressed.

6) Installation methods that are not allowed for driven piles and/or steel shells of CIDH piles. Examples of statements include:
   a) Vibratory hammers, jetting, predrilling, or methods other than driving by impact hammers are not allowed for driven piles.
   b) Oscillating or vibratory hammers are not allowed for driving permanent steel shells of CIDH piles (for which axial and/or lateral capacities are required).

7) Anticipated problems or difficulties from pile driving.

These problems or difficulties may come from overhead clearance, overhead and underground utilities, hard driving, vibrating or driving noise, schedule constraints, etc. Examples of solutions to these problems include:

a) predrilling or center-relief for hard driving (include elevation limits and maximum diameters as applicable);
b) vibrating steel casings to reduce construction time and casing thickness when no axial and/or lateral capacity are required for these casings;
c) jetting to below liquefiable soil layers or the maximum scour depth to reduce construction time; or
d) replacement of driven piles with Caltrans-approved alternative pile systems (for example, Fundex piles) to accommodate overhead clearance or reduce driving noise.

8) Effects of construction work on adjacent structures.
Efforts shall be made to minimize effects of construction work on adjacent structures. These situations may result from pile-driving vibration, settlement due to de-watering or excavation, or caving due to CIDH pile drilling. A monitoring program may be required for pile driving at, or adjacent to, existing structures that are susceptible to damage or sensitive to noise and/or vibration to assure a presumptive threshold will not be exceeded. If such hazards exist, either protection measures against damage or alternative foundation types shall be discussed.

3.14 Appendices

As an integrative part of the Foundation Report, appendices provide detailed information supporting foundation design, analyses, recommendations, and construction considerations. These shall contain, not to be limited to the following:

1) Appendix I - Site Map, Field Exploration, and Log of Test Borings
   a) site map indicating project location;
   b) data acquired from field exploration such as logs from the Cone Penetration Test, Pressuremeter Test, Dilatometer Test, In-situ Vane Shear Test, Downhole Suspension Logging, Downhole Electric Logging (Natural Gamma, Resistivity, and Caliper Logging), Downhole Acoustic Televiewer Logging, Foundation Load Test, Piezometer Readings, etc.; and
   c) full-sized Log of Test Borings sheets, including As-Built LOTB.

2) Appendix II - Laboratory Testing Results
   a) descriptions of each type of soil test and a summary of the results,
   b) geotechnical soil laboratory test results, and
   c) corrosion test results.

3) Appendix III - Analyses and Calculations
Engineering analyses and calculations supporting the foundation recommendations shall be included. Legible, coherent, and numbered calculation sheets shall contain the dates and initials of the geotechnical professional who performed or checked the analyses and calculations. These shall include, but not to be limited to the following:

a) bearing capacity, stress distribution, settlement, sliding resistance, uplift, and overall stability calculations for spread footings; vertical, horizontal, rotational, and/or torsional soil springs and damping ratios for footings as required by structural designers;
b) axial pile capacity and settlement calculations: compression, tension, down-drag force, considerations for potential liquefiable soil and maximum scour depth, and/or group pile capacity and settlement; graphic presentation of proposed axial pile capacity along pile length;
c) estimated driving resistance: when specific pile tips are controlled by lateral demand, presence of liquefiable soil, down-drag force, and/or scour consideration;
d) lateral pile capacity calculations: input parameters or files for COM624/LPILE/GROUP or an equivalent analysis, considerations and/or assumptions for the lateral soil modulus parameter (k), soil strain parameter (ε_{50}), p-y curves for liquefiable soils and weak rocks, distributed lateral soil pressures along pile lengths due to slope instability, lateral forces due to liquefaction, reduction factors or efficiency for pile groups, pile head boundary conditions, and loads; summary output plots (not entire output data) including deflection, moment, and shear profiles along pile length, pile head force versus pile head deflection and pile maximum moment as appropriate, point of pile fixity as required by structural designers; p-y, t-z, and Q-Z curves as required by structural designers;
e) liquefaction evaluation: assumptions, references for correlation relationships, and conclusions; foundation support locations and zones (e.g., bents, stations, and elevations) subjected to the liquefaction hazard shall be listed or tabulated;
f) slope stability analysis: input files including soil cross-section profiles for STABL or an equivalent analysis, analytical models and assumptions for estimating permanent deformation under static and dynamic loading conditions;
g) soil resistance against abutments;
h) settlement calculations for approach fills: type and amount of settlement as well as settlement period with or without pre-loading and/or de-watering; and
i) recommended *SDC* response spectra or modified versions.

4) Appendix IV - References. For consultant-prepared Foundation Reports, include Caltrans Review Comments and Consultants Responses.

4. LOG OF TEST BORING (LOTB) SHEETS

LOTB and As-Built LOTB plan sheets shall be prepared and included as part of the Foundation Report and Contract Plans when foundation work is part of the contract. Examples of an LOTB and As-Built LOTB sheets are shown in the documents "SampleLOTB" and "SampleAsBuiltLOTB."

4.1 Check List for Preparation of LOTB Sheets

LOTB sheets shall be drafted in accordance with Section 15-3 of *Bridge Design Aids* (Caltrans, 1989) and Section 2-2.24 of *Plans Preparation Manual* (Caltrans, 2001c). LOTB sheets should be checked by the person who performed the field investigation and approved by a Registered Civil Engineer or Registered Geologist, either of whom shall have experience in foundation engineering. The LOTB sheet shall contain, but not to be limited to the following:

1) Signature Block (Upper Right Corner):
   a) the State of California Registered Civil Engineer or Registered Geologist seal with the signature, license number, and registration certificate expiration date of the engineer or geologist in charge of the foundation study;
   b) Caltrans District, County, and Route;
   c) name and address of consultant firm performing the foundation investigation (if applicable);
   d) name and address of the lead local agency (if applicable); and
   e) a disclaimer stating "The State of California or its officers or agents shall not be responsible for the accuracy or completeness of electronic copies of this plan sheet."

   Kilometer Post Total Project limits, Sheet Number, Total Sheets, and Plans Approval Date shall be provided by the Office Engineer.

2) Legend Block (Left Side):
   a) consistency/relative density classification for granular and cohesive soils according to Standard Penetration Test (SPT);
   b) a legend of the earth materials;
   c) a note such as "Visual classification of earth materials is based on field inspection and is confirmed or revised with laboratory test results as necessary;"
   d) a legend of in-situ, lab, and field test designations; and
   e) a legend of types of borings and boring operations.

3) Title Block (Bottom, from left to right):
   a) notes stating "ENGINEERING SERVICES" and "GEOTECHNICAL SERVICES." For consultant-prepared LOTB sheets, instead of those notes, show the name of the Design Oversight (i.e., OSFP/OSCM Senior Liaison) Engineer and sign-off date.
   b) the name of the person preparing the LOTB sheet and the name of the person checking the drawing;
   c) the name(s) of the field investigator(s);

d) a note stating "STATE OF CALIFORNIA, DEPARTMENT OF TRANSPORTATION" with a scale below the sub-block and a label on the left side stating "ORIGINAL SCALE IN MILLIMETERS FOR REDUCED PLANS." For consultant-prepared LOTB sheets, the note shall state "PREPARED FOR THE STATE OF CALIFORNIA, DEPARTMENT OF TRANSPORTATION."

e) a note stating "STRUCTURE DESIGN." For consultant-prepared LOTB sheets, instead of this note, show the name of the Project Engineer;

f) the Caltrans Contract Expenditure Authorization (CU and EA) numbers;

g) the State-assigned Bridge (or Structure) Number, Kilometer Post, and the State-assigned Bridge (or Structure) Name;

h) the initial drawn by and subsequent revision dates; and

i) a label stating "LOG OF TEST BORINGS _ OF _" (if applicable). The project LOTB sheets (and Rock Legend sheet, if applicable) shall be followed by As-Built LOTB sheets when applicable.

The Sheet Number and Total Sheets Number will be provided by the Office Engineer.

4) Plan View

a) Show the Plan View at the top of the first LOTB sheet. When the site is sufficiently large or complex, the first LOTB sheet may be used entirely for the Plan View.

b) When multiple LOTB sheets are drafted, they shall be numbered with reference to the stationing of the control line (i.e., showing sheet No. 1 with the lowest stationing and the last sheet with the highest stationing).

c) A distinct Plan View of the project site that is independent of the Profile View shall be shown on the LOTB.

d) Field exploration completed shall be tied to a nearby benchmark. Show the location, description, and elevation of the benchmark used for determining the top of boring elevations at the top left side of the Plan View.

e) Identify the datum (National Geodetic Vertical Datum, U.S. Geological Survey, U.S. Coast & Geodetic Survey, District, etc.) used to determine the benchmark elevations.

f) Show the metric scale directly below the Plan View label.

g) Show a North arrow.

h) Lines or control lines shown in the Plan View shall be consistent with those shown on the General Plan sheet.

i) Show a minimum of two stations on all lines.

j) Show stationing and names for control lines. Stationing shall increase from left to right.

k) Show control line intersection stationing and bearings.

l) Show names and directions of nearest cities.

m) Show names and directions of stream flows when applicable.

n) Show the beginning of curve (BC) stationing and end of curve (EC) stationing. When BC and EC locations are beyond the View limits, their locations shall be noted in the Plan View.

o) Superimpose the structure support locations (as provided by Structure Design).
p) Plot boring locations with symbols as shown in the legend to identify drilling methods (e.g., auger hole, bucket hole, rotary, cone penetration).
q) Boring locations may be identified by number, coordinates (Northings and Eastings), or reference line, station, and offset.
r) Borings shall be uniquely numbered for each project.

5) Profile View
   a) Show the control line, increasing from left to right, horizontally across the bottom of the Profile View.
   b) Borings shall match the numbering shown in the Plan View.
   c) Show the boring's number, top elevation, stationing, and offset at the top of each boring log.
   d) Show types and diameters of bore holes of each boring with symbols as shown in the legend.
   e) Show the completion date of boring at the bottom of each boring log.
   f) Show dates and elevations of groundwater readings. When groundwater was not encountered (or measured) at the site, add a note stating "Groundwater was not encountered (or measured)" at the bottom of the boring log.
   g) Show results from field tests and results from moisture and density tests at relevant elevations along the boring log.
   h) Show types of laboratory tests, with symbols as indicated in the legend, at relevant elevations along the right side of the boring log.
   i) Show results from any other in-situ testing or logging (suspension logging, electric logging, etc.).
   j) Show the approximate current ground surface line. Future fills shall not be included.
   k) Show the Profile metric scales (horizontal and vertical).

6) Show the following information when applicable:
   a) Soil and rock logging system.
   b) Rock Legend Standard Sheet.
   c) Descriptions of types, and inside and outside diameters of the samplers used for the field exploration, and the elevations where the samplers changed.
   d) Descriptions of hammer type and weight, lift and drop method, and drop height.
   e) Metric units shall be used for all LOTB sheets.
   f) A "Metric" symbol must be placed next to the signature block for metric jobs.

4.2 Check List for Preparation of As-Built LOTB Sheets

The As-Built LOTB sheet(s) shall be prepared and included in the Foundation Report and Contract Plans for widening, replacing, or retrofitting existing bridges when existing LOTB sheets are available. For a new structure to be constructed in close proximity of an existing structure, the As-Built LOTB sheet(s) of the existing structure may be included with the new set of plans, especially if the foundation information was used to develop recommendations in the Foundation Report. In preparing a copy of the As-Built Log of Test

Borings sheet, use a process that will result in a final black line reproducible sheet of a high quality.

1) Obtaining and Reproducing the As-Built LOTB Sheet
   a) Reproducible copies of As-Built LOTB sheets may be obtained from the Microfilm Services Units in the Caltrans District Offices. If the As-Built LOTB sheets provided to Local Agencies or consultants by the Caltrans District Offices are not legible, a full sized copy can be requested from Geotechnical Services.
   b) As-Built LOTB sheets shall be size "D" (24" by 36"). The As-Built LOTB title block shall be sized to fit and placed at any open space (preferably toward the top) on the As-Built LOTB sheet.
   c) Information on the As-Built LOTB sheet shall be as clear and readable as possible. In order to improve the legibility of the information, it may be necessary to darken the line work and the notations.

2) Typical Modifications to As-Built LOTB Sheets
   a) Show a "Metric" notation next to the signature box if any metric conversion, notation, or notes have been made.
   b) If As-Built LOTB sheets are shown in imperial units, the offset and stationing location of each boring must be converted to metric. A table shall be added showing the dual dimensions (Metric and English) of each boring. The table shall show the station and offset in relation to the new metric line. The General Plan will show the current metric control line.

3) The As-Built LOTB Title Block (Figure 2) shall include the following information for the current project:
   a) A note stating "GEOTECHNICAL SERVICES -- DIVISION OF ENGINEERING SERVICES" (if applicable).
   b) Caltrans District, County, Route, Kilometer-Post Total Project limits, State-assigned Bridge (or Structure) Number and Name, and Expenditure Authorization (CU and EA) numbers. The Sheet Number and Total Sheets Number will be provided by the Office Engineer.
   c) The State of California Registered Civil Engineer or Registered Geologist seal with the signature, license number, and registration certificate expiration date of the engineer or geologist in charge of the foundation study.
   d) A note stating "As-Built Log of Test Borings sheet is considered an informational document only. As such, the State of California registration seal with signature, license number and registration certificate expiration date confirm that this is a true and accurate copy of the original document. It does not attest to the accuracy or validity of the information contained in the original document. This drawing is available and presented only for the convenience of any bidder, contractor or other interested party."
   e) A sub-box stating "LOG OF TEST BORINGS _ OF _" (if applicable).
   f) A note stating "A COPY OF THIS LOG OF TEST BORINGS IS AVAILABLE AT OFFICE OF STRUCTURE MAINTENANCE AND INVESTIGATIONS, SACRAMENTO, CALIFORNIA" (if applicable).

Examples of LOTB and As-Built LOTB sheets are shown in the documents "SampleLOTB" and "SampleAsBuiltLOTB". Additional information regarding LOTB and As-Built LOTB sheets can be found in Section 15-3 of *Bridge Design Aids* (Caltrans, 1989) and Section 2-2.24 of *Plans Preparation Manual* (Caltrans, 2001c).

5. CONTRACT PLANS

The foundation data provided on the Contract Plans shall be consistent with information contained in the Foundation Report. The following information for specific foundation types shall be provided in the Contract Plans.

5.1 Acceleration Response Spectra (ARS)

The design ARS curve(s) shall be shown on Contract Plans. The design ARS curve(s) shall be consistent with that/those shown on Foundation Reports.

If Fault Rupture is assumed to be part of the site-specific design criteria, then recommendations for horizontal and vertical fault rupture displacements shall be noted in the General Notes of the Contract Plans. Rupture displacements shall be consistent with those shown in the Fault Rupture Study as part of the Preliminary and Final Foundation Reports.

5.2 Pile Foundations

A Pile Data Table as illustrated in *Bridge Memo to Designers 3-1* (Caltrans, 2000b) containing required design information shall be included in the Contract Plans. When space is available, the pile data table shall be shown on the General Plan (GP). If not, the pile data table shall be shown on subsequent available pages.

5.3 Spread Footings

When spread footings are to be used to support all or any portion of the structure, the following specific design parameters for the footings shall be included on the Contract Plans:

1) For abutment locations: Gross Allowable Soil Bearing Pressure (q_{ALL}) and Maximum Contact Pressure (q_{MAX}).
2) For bent/pier locations: Ultimate Soil Bearing Pressure (q_U), Maximum Contact Pressure (q_{MAX}), and Strength Reduction Factor (ϕ).

The Ultimate Soil Bearing Capacity (q_{ULT}) and a Spread Footing Data Table shall be included in the Foundation Report.

The format for presenting the design parameters shall be in accordance with the latest *Bridge Memo to Designers* (or similar Caltrans publication), when published. Until such time, the Spread Footing Data Table shown in Figure 3 may be used in the Foundation Report.

5.4 Log of Test Boring Sheets

1) Signed, approved final LOTB sheets shall be included in the Contract Plans.
2) Signed, legible As-Built LOTB sheets shall be included in the Contract Plans following the new LOTB sheets.

6. FIGURES

Figure 1. Typical Section: Expansive Soil Exclusion Zone in Bridge Embankment

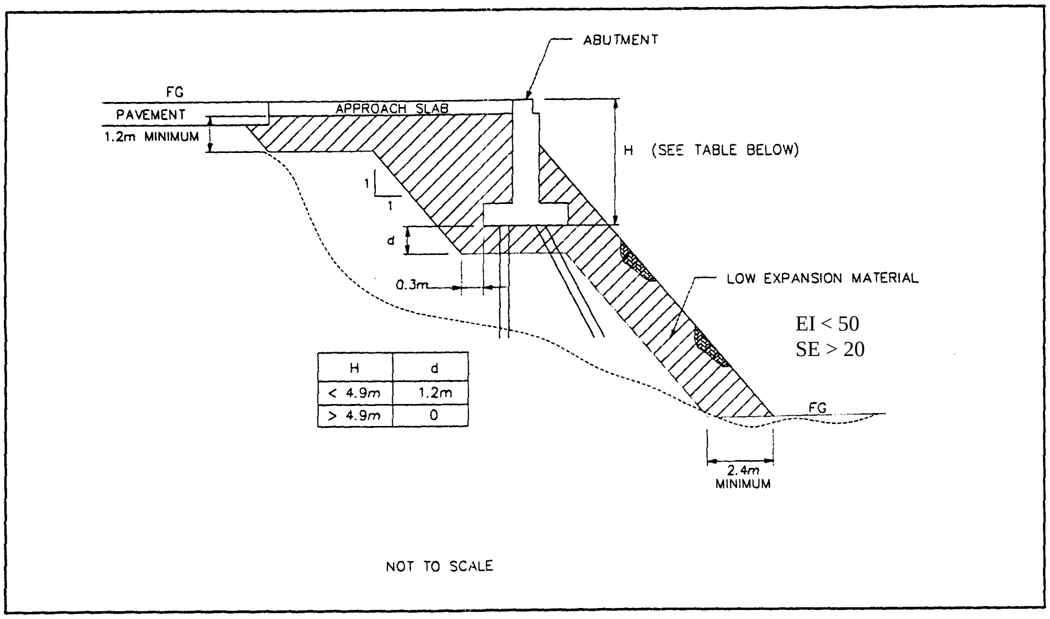

Figure 2. Title Block for As-Built Log of Test Borings

GEOTECHNICAL SERVICES -- ENGINEERING SERVICES

As-Built Log of Test Borings sheet is considered an informational document only. As such, the State of California registration seal with signature, license number and registration certificate expiration date confirm that is this a true and accurate copy of the original document. It does not attest to the accuracy or validity of the information contained in the original document. This drawing is available and presented only for the convenience of any bidder, contractor or other interested party.

DIST.	COUNTY	ROUTE	KILOMETER POST – TOTAL PROJECT	SHEET NO.	TOTAL SHEETS
08	SBd	210	10.00-15.00	24	25

REGISTERED ENGINEER -- CIVIL

MAIN STREET OVERCROSSING

LOG OF TEST BORINGS 5 OF 6

NOTE: A COPY OF THIS LOG OF TEST BORINGS IS AVAILABLE AT OFFICE OF STRUCTURE MAINTENANCE AND INVESTIGATIONS, SACRAMENTO, CALIFORNIA	CU: 01234 EA: 12-345678	BRIDGE NO. 12-3456

Figure 3. Spread Footing Data Table

Spread Footing Data

Support Location	Minimum Footing Width	Bottom of Footing Elevation	Recommended Soil Bearing Pressure	
			WSD[1]	LFD[2]
			Gross Allowable Soil Bearing Pressure (q_{ALL})	Ultimate Soil Bearing Pressure (q_U)
Abut 1			XX kPa (YY ksf)	N/A
Bent 2			N/A	XX kPa (YY ksf)
Pier 3			N/A	XX kPa (YY ksf)
Abut 4			XX kPa (YY ksf)	N/A

Notes: 1) Working Stress Design (WSD). The Maximum Contact Pressure, q_{MAX}, is not to exceed the recommended Gross Allowable Soil Bearing Pressure, q_{ALL}. The Ultimate Soil Bearing Capacity, q_{ULT}, will equal or exceed 3 times the recommended Gross Allowable Soil Bearing Pressure, q_{ALL}.

2) Load Factor Design (LFD). The Maximum Contact Pressure, q_{MAX}, divided by the Strength Reduction Factor, ϕ, is not to exceed the recommended Ultimate Soil Bearing Pressure, q_U. The Ultimate Soil Bearing Capacity, q_{ULT}, will equal or exceed the recommended Ultimate Soil Bearing Pressure, q_U.

7. REFERENCES

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